Solar System Exploration Division, GSFC Code 690

A high-resolution global map of lunar gravity from patched local solutions using GRAIL data

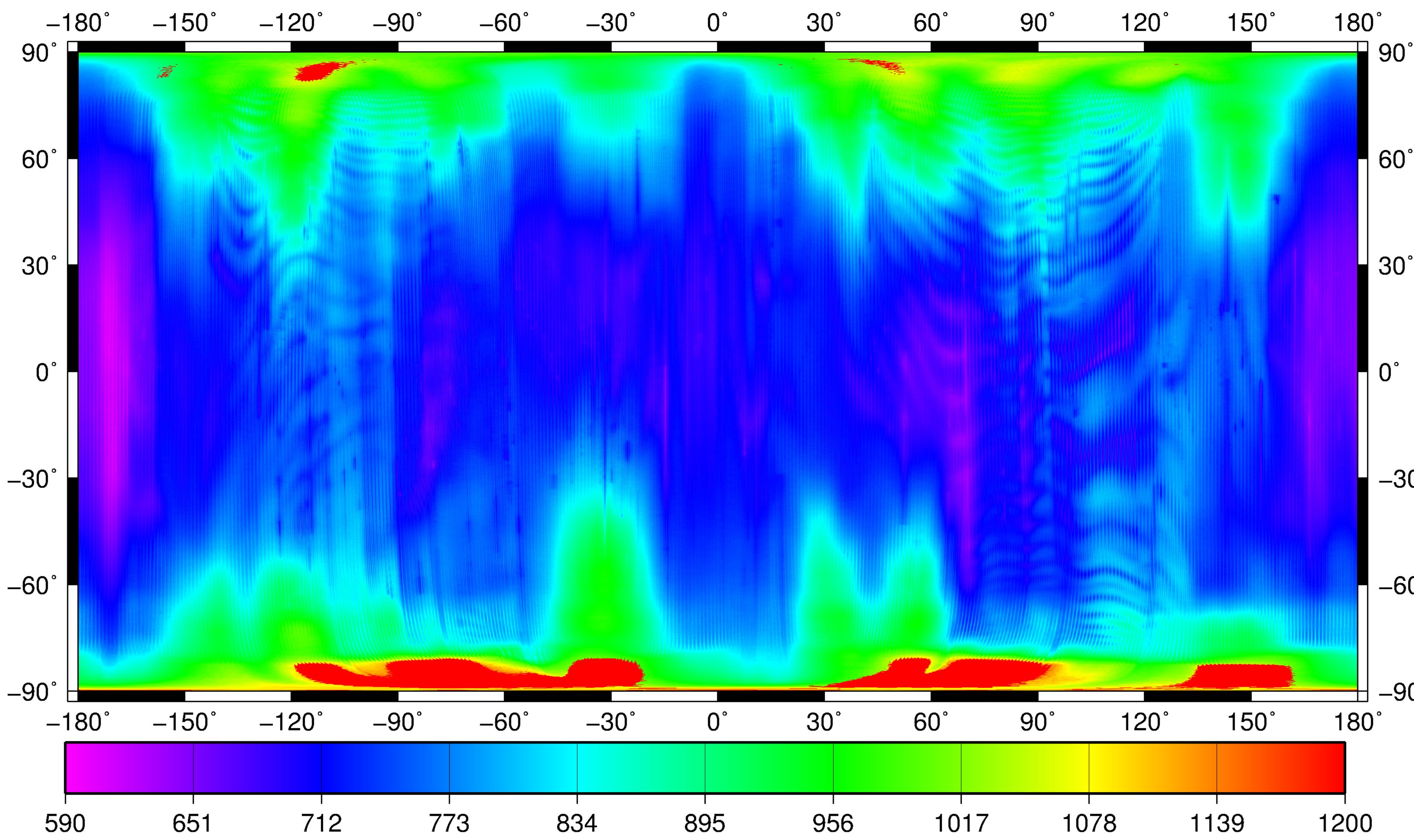
Sander Goossens [1,2], Terence .J. Sabaka [3], Álvaro Fernández Mora[1,2,4], Eduard Heijkoop[1,2,4]

[1]CRESST/UMBC, [2]NASA GSFC, Code 698, [3]NASA GSFC, Code 61A, [4]Delft University of Technology, the Netherlands
(email: sander.j.goossens@nasa.gov)

Introduction

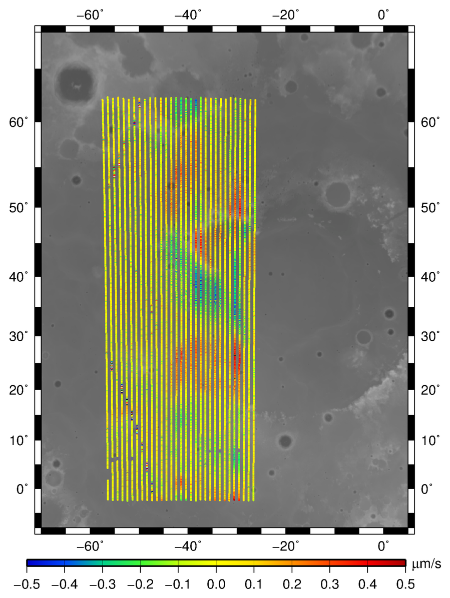
The primary science objectives of the Gravity Recovery and Interior Laboratory (GRAIL) mission are to determine the structure of the lunar interior from crust to core and to advance the understanding of the thermal evolution of the Moon. These objectives are to be achieved by producing a high-quality, high-resolution map of the gravitational field of the Moon. **The concept of the GRAIL mission and its measurements is based on the successful GRACE mission** which mapped the gravity field of the Earth: the distance between two co-orbiting spacecraft was measured precisely **using a Ka-band ranging system (KBRR)**, augmented by tracking from Earth using the Deep Space Network (DSN).

The GRAIL mission consisted of two separate phases: a primary mission phase, which lasted from March 1, 2012 until May 29, 2012, where the spacecraft were at an average altitude of 50 km above lunar surface, and an extended mission phase, which lasted from August 30, 2012, until December 14, 2012, during which the average spacecraft altitude was 23 km. In the latter part of the extended mission this altitude was lowered further to 20 km (November 18) and finally 11 km (December 6). Using these data, several models expressed in spherical harmonics have been determined, with current maximum resolutions of degree and order 1200 or 1500. However, the effective resolution of these models varies spatially because of varying spacecraft altitude and ground track spacing. **Global spherical harmonics are not optimal when the spatial data coverage is heterogeneous**, because they require smoothness constraints that are commonly applied to the entire model. In such instances, local methods of gravity recovery are advantageous: **constraints can be applied locally**, and in addition **require fewer computational resources**. Here, we present the results of a fully localized analysis of GRAIL tracking data, resulting in a global map of lunar gravity that delineates features clearer than an equivalent global model, and **that has improved correlations with** the Lunar Reconnaissance Orbiter's Lunar Orbiter Laser Altimeter (LOLA) **topography**.



Degree strength, which is a measure of the geographically varying resolution of a model, for the GRAIL GRGM1200A model. A higher degree strength in a location indicates a better resolution of the model.

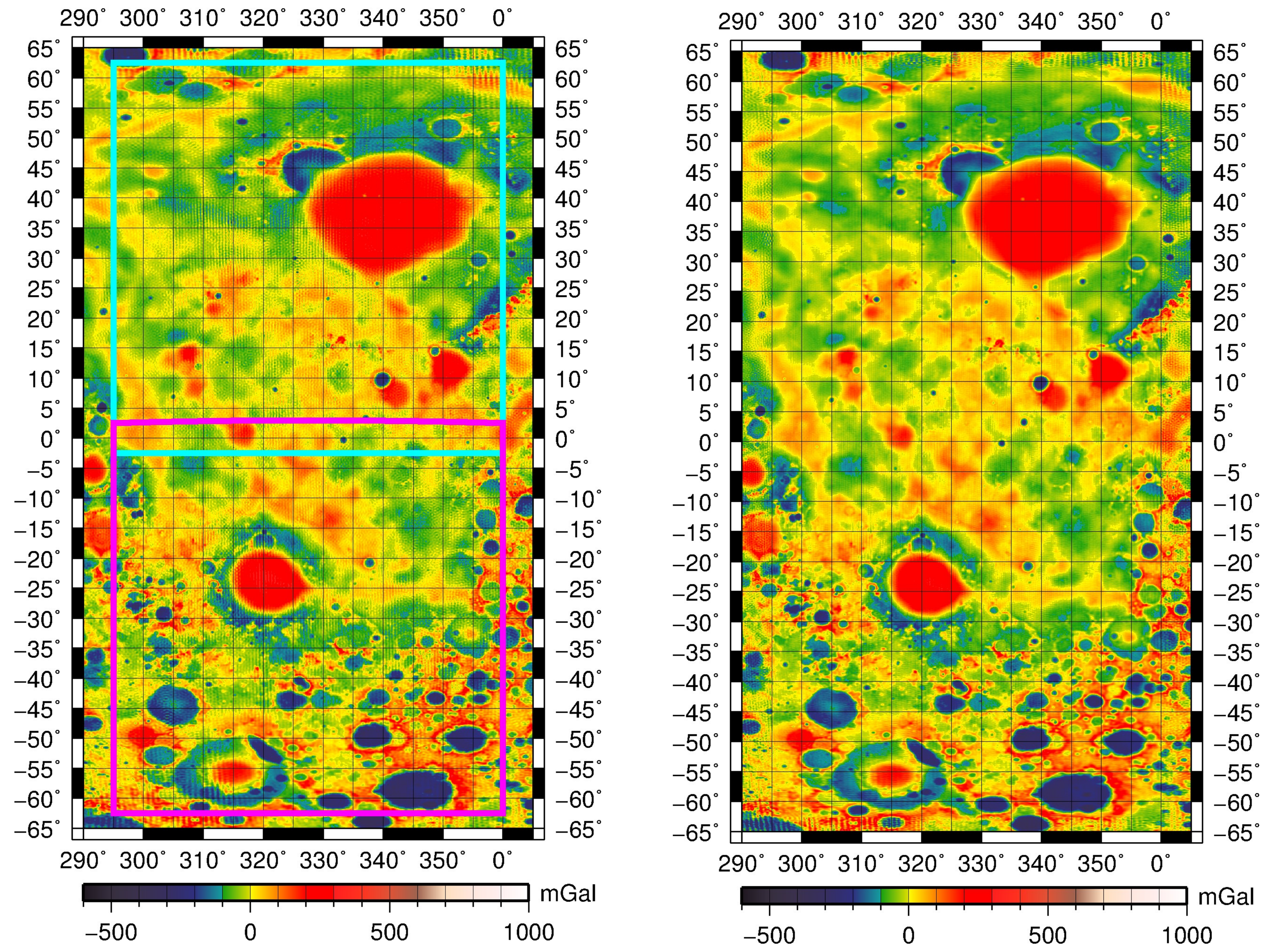
Processing strategy



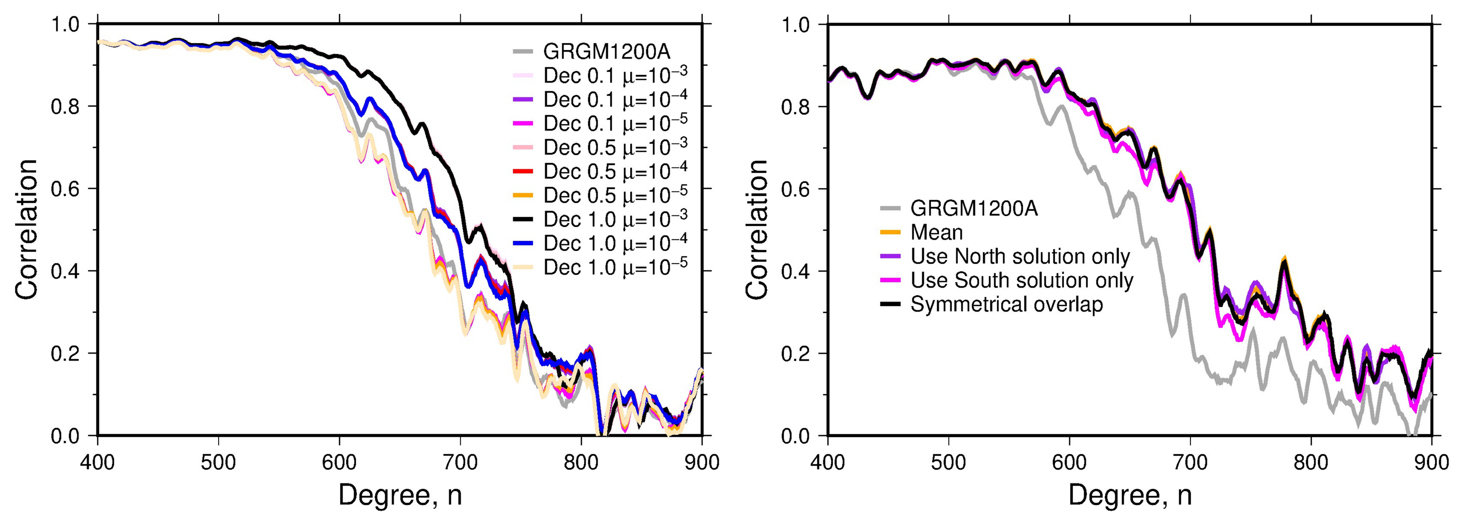
KBRR residuals over a selected area.

We have implemented **a localized method that uses gridded gravity anomalies** (to describe gravity signal in addition to the background global model), which are **estimated from KBRR data only**, selected above the area of interest. We have demonstrated this method for a solution covering the south pole of the Moon (*Goossens et al.* (2014), GRL). We determine the satellite orbits using both KBRR and DSN data for a span of on average two and a half days. From these orbits, **we select the times that the satellite pair's ground track covers the area of interest**, which results in spans (called arcs) much shorter than the initial arcs (on average their duration is ~22 minutes). **We re-determine the orbits for these short arcs using only KBRR data.** When these orbits are re-determined, we generate partial derivatives of the KBRR measurements with respect to the gravity anomalies. We then form a system of normal equations to estimate the anomalies. **We apply a neighbor smoothing constraint to this system**, where **we smooth the full gravity anomaly**, which consists of the contribution of the global background model and the new adjustments. Applying this constraint to the full anomalies instead of to the adjustments only has several advantages: it results in smoother maps of gravity, and improved correlations with topography.

Selecting local solutions

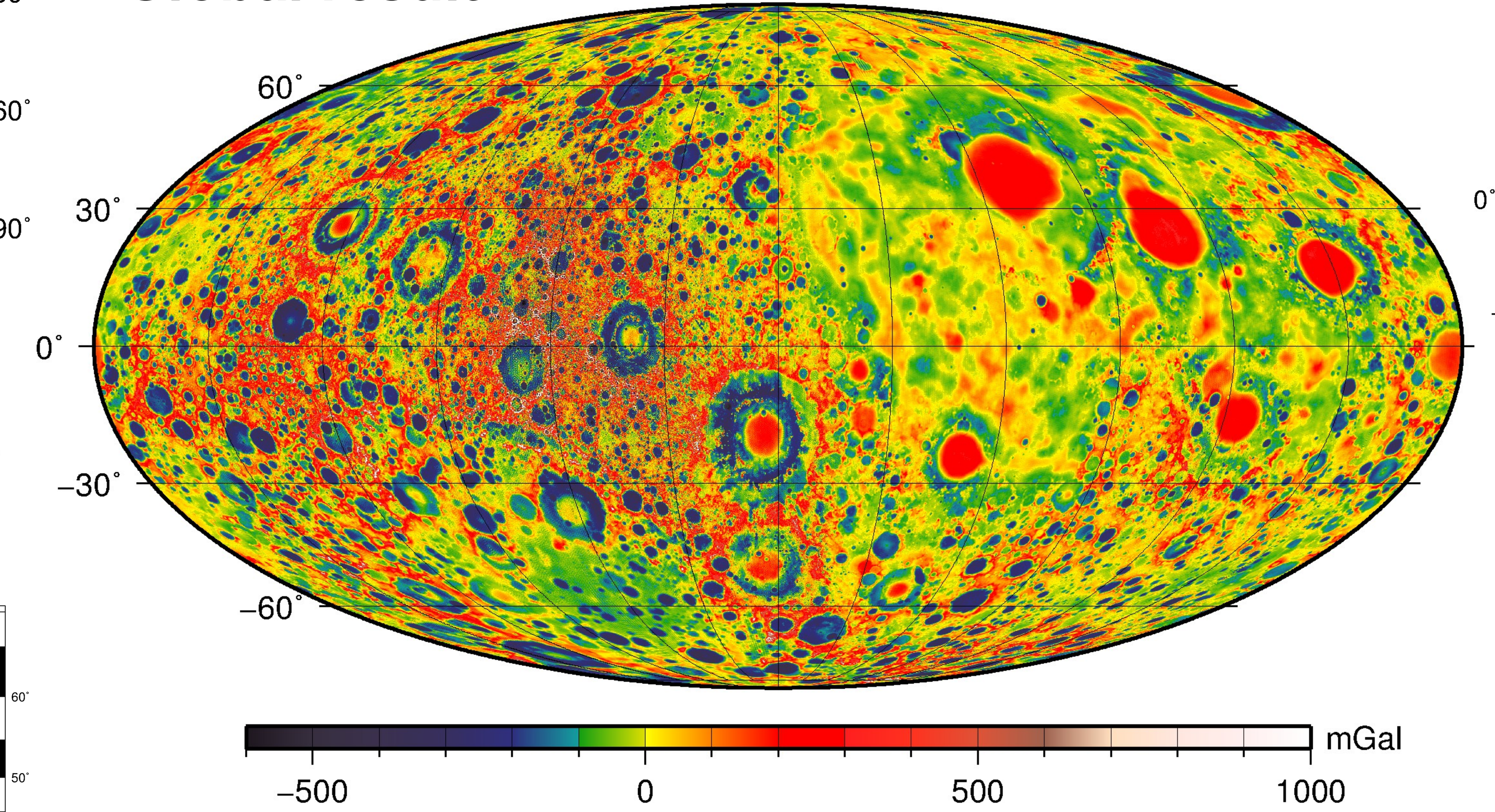


Gravity anomalies from start solution (GRGM1200A) and local solution areas indicated (left), and combined patched local solution (right).

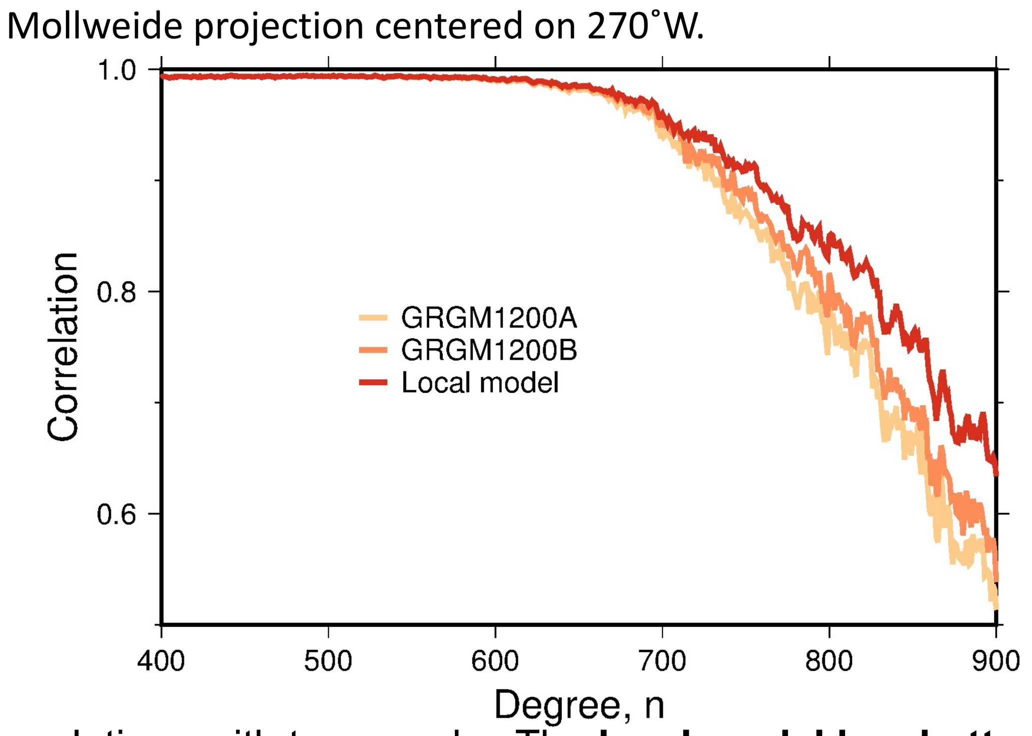


We use localized correlations with topography (an independent measure) to determine which neighboring constraint factor (left) or patch method (right) to use. Larger constraint factors mean stronger smoothing.

Global result

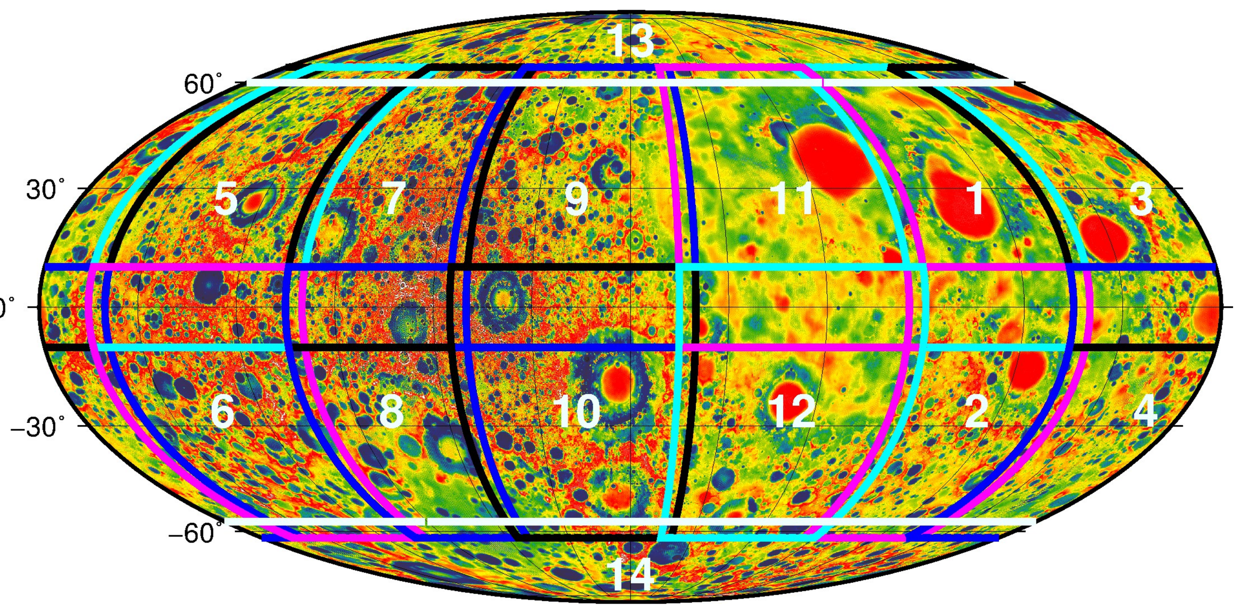


The global map of lunar gravity consisting of patched local solutions. The map is in Mollweide projection centered on 270˚W.

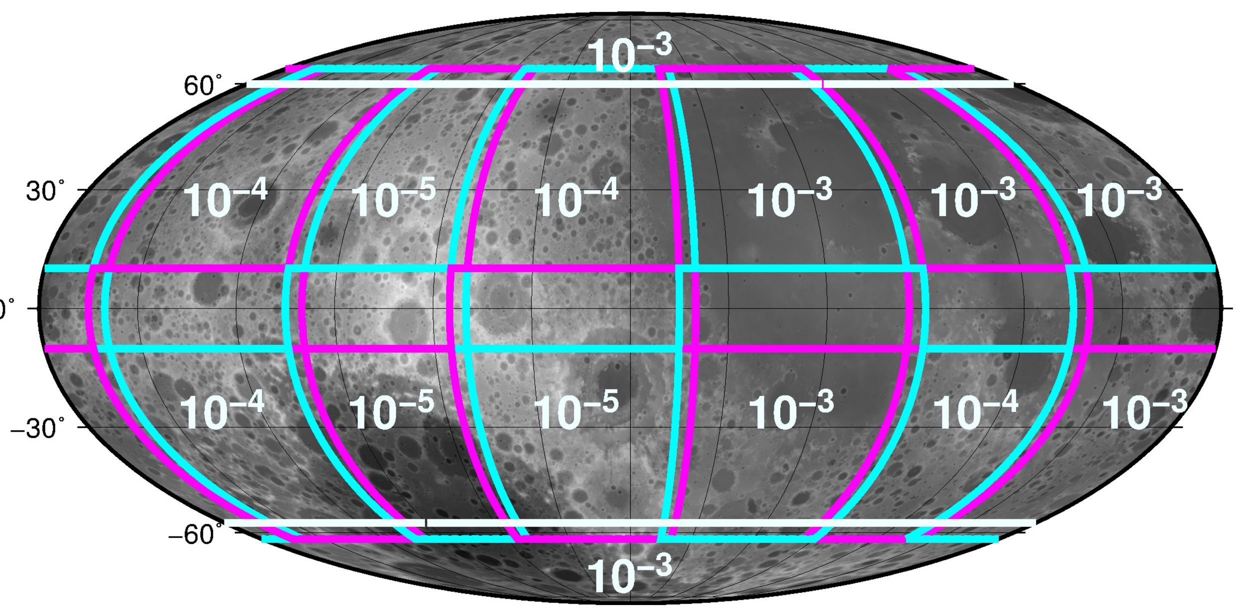


Global correlations with topography. The **local model has better correlations** than the start model and than an iterated global model.

Generating and patching local solutions

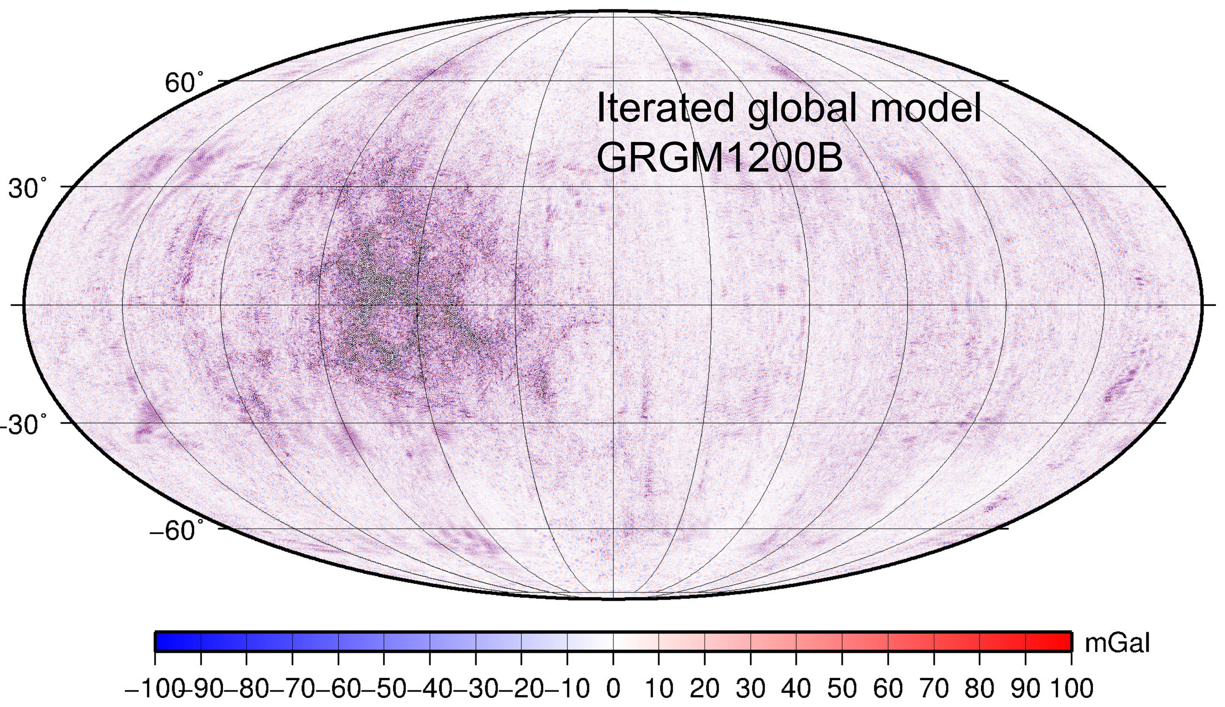


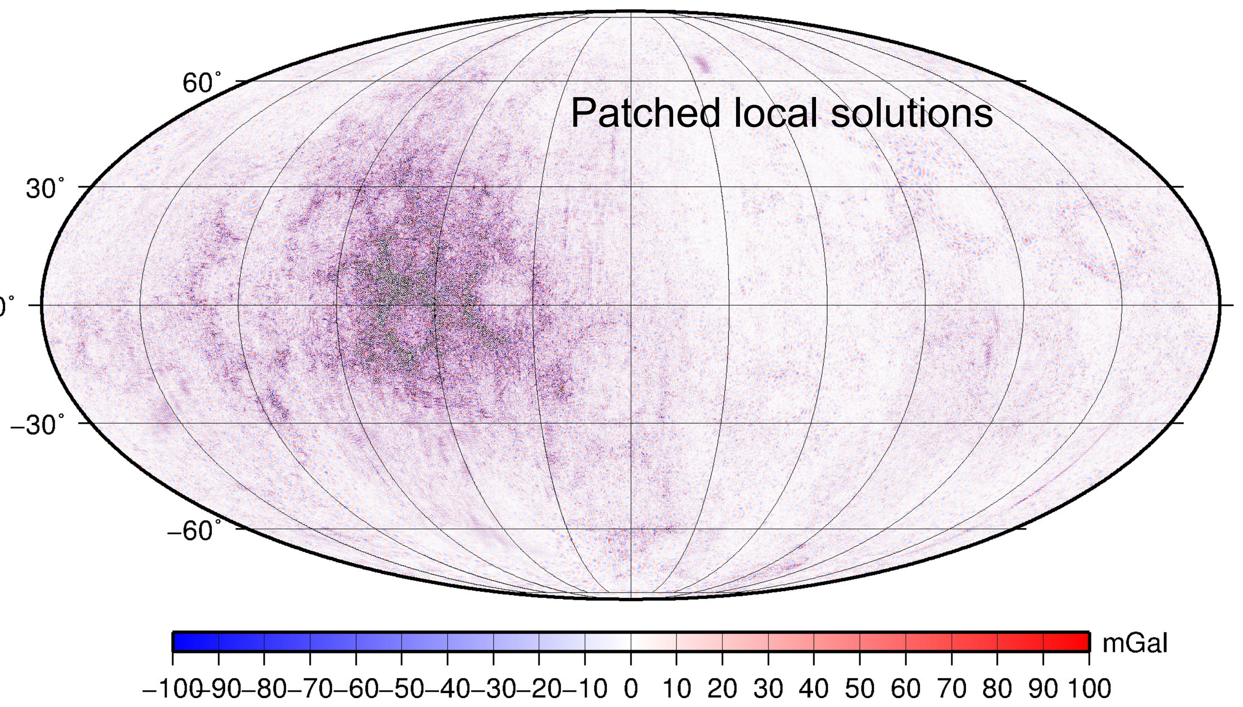
Separate areas for which local solutions will be determined. Each area overlaps with its neighboring area. The poles are covered by caps. We have 14 areas in total for which we make separate solutions that are then patched.



For each area, we generate multiple solutions using different neighboring constraint factors. We evaluate each solution (see correlations plot on the left) and then decide which factor to apply.

Model evaluation





Gravity anomaly differences between the solutions and gravity-from-topography, between spherical harmonic degrees *n*=150-900 (filtered Bouguer anomalies). The local solution shows fewer stripes, which is also indicated by better correlations with topography (plot on left). Remaining differences indicate crustal density differences, among others.

We thank the **NASA Center for Climate Simulation (NCCS)** at Goddard for the use of their supercomputers.